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Survey of phytophagous insects and foliar pathogens in China for a biocontrol perspective on kudzu, *Pueraria montana* var. *lobata* (Willd.) Maesen and S. Almeida (Fabaceae)

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Abstract

A three-year survey of kudzu foliage, seed, stems, and roots for associated phytophagous insects was conducted to establish basic information about the insect communities that kudzu harbors in China and to assess the abundance, diversity and damage caused by these insects. Diseases of kudzu were also surveyed in southern China. A total of 116 phytophagous insect species in 31 families and 5 orders were collected from kudzu in China, in six feeding guilds: foliage, sap, stem, terminal, seed and root feeders. The impact of foliage feeders varied from site to site and year to year, and over the course of the growing season. The mean percent defoliation of kudzu over all plots and years was $13.3 \pm 1.9\%$, but ranged as high as 34%. Two insect species fed on shoots and clipped off terminals. Infestation of new shoots was high, with nearly half of all shoots clipped. Nearly half of the vines showed damage from stem borers, again varying through the season. Two species of insects attacked kudzu roots, mainly the cerambycid beetle *Paraleprodera diophthalma* (Pascoe), which caused considerable damage to both small (young, <3.4 cm diameter) and large (older, >6 cm diameter) roots. Insects also caused substantial seed damage. Imitation rust, caused by *Synchytrium minutum* [= *S. puerariae* (P. Henning) Miyabe], was the most commonly observed disease of kudzu. Several of these species have potential as biological control agents for kudzu in the US.

Keywords: Feeding guilds; Biological control; Weeds; Invasive species

1. Introduction

Kudzu, *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen and Almeida (Ward, 1998a), is an invasive exotic weed in the United States. A perennial, semi-woody, climbing leguminous vine, this species is of great concern in the southeastern United States (Forseth and Teramura, 1987; Holm et al., 1979; Patterson, 1976), but ranges from Florida to Massachusetts and west to Oklahoma and Texas (Frankel, 1989; Mitich, 2000). New infestations have recently been reported in Oregon and Washington State (Washington State Noxious Weed Control Board, 2003).

Kudzu is native to and widely distributed in China except in the Xiangjiang Autonomous Region, Quinghai, and Tibet. Two other closely related varieties (generally considered species by Chinese botanists), *P. montana* var. *montana* and *P. montana* var. *thomsonii* (Ward, 1998b) are distributed mostly in the southern part of China. Kudzu can be found at elevations between 300 and 1500 m with the most common sites at low elevations including roadsides,

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tree plantations, clear-cut areas or any open land (Zhang and Wang, 1999). Kudzu is a short-daylight plant and grows well with precipitation of 1000–1500 mm on sand or clay soil. Its deep and well-developed root system enables kudzu to grow in very dry sites and in poor soil (Zhang and Ye, 1990). Shao (1993) estimated that kudzu is found on approximately 20 million ha in China. Although kudzu is widely distributed in China, there are no references to kudzu as a weedy pest problem there, probably because of suppressive factors such as herbivorous insects, and because the plant is economically important. In addition to its use in food preparation, brewing alcoholic beverages (Shao, 1993), and medicines (Yang et al., 1996), kudzu has been used in China for soil erosion control and soil improvement (N-fixation) (Yang et al., 1990; Zhang, 1987), livestock forage (Zhang, 1987; Zhang and Gu, 1998; Zhu, 1996), rope (authors' observations), and clothing in ancient times.

Kudzu was originally introduced into the United States as an ornamental vine in 1876 at the Philadelphia Centennial Exposition (Winberry and Jones, 1973), then as a forage crop at the beginning of the 20th century (Piper, 1920). A variety of studies have shown that kudzu is both high in quality and palatable to livestock (Corley et al., 1997; Duke, 1981; Ensminger and Olentine, 1978). However, widespread distribution of kudzu did not occur until the 1930s and '40s, when it was promoted by the USDA Soil Conservation Service for soil erosion control, especially in the Piedmont regions of Alabama, Georgia and Mississippi (Tabor and Susott, 1941). By 1953, kudzu was recognized as a weed and removed from the list of species recommended for use under the Agricultural Conservation Program. By 1970, it was listed as a common weed in the southeastern United States (Everest et al., 1999), and today is listed as a noxious weed in at least nine states. Estimates of the current kudzu infestation in the US vary considerably, from several hundred thousand to over 10 million acres (4.05 million ha), but the most commonly cited figure is around 7 million acres (2.84 million ha) (Britton et al., 2002; Corley et al., 1997; Everest et al., 1999; Fears and Frederick, 1977; Miller and Edwards, 1983; Mitich, 2000) and the infestation continues to spread. Kudzu is widely believed to drastically reduce biodiversity because of its ability to smother other vegetation and develop large-scale monocultures (Alderman, 1998), although quantitative investigations are lacking (Forseth and Innis, 2004). Matlock (2002) reported expert consensus in Mississippi that kudzu posed one of the most serious threats to natural areas due to its ability to overwhelm natural vegetation.

Various management and eradication programs have been explored to control the spread of kudzu in the US, including intensive herbicide application (Harrington et al., 2003; Miller, 1996; Miller and Edwards, 1983), livestock grazing (Bonsi et al., 1992), industrial use of the plant (Tanner et al., 1979), and use of the plant pathogen *Pseudomonas syringae* pv. *phaseolicola* (Britton et al., 2002). Although modern herbicides effectively kill kudzu (Harrington et al., 2003; Thomas, 2000), substantial and sustained effort is required, because anything short of complete eradication will allow rapid reinfestation (Mississippi State University, 2001).

Biological control of kudzu has only recently been considered as a possible management strategy. Kudzu appears to be a good candidate for classical biological control, since this naturalized weed lacks natural enemies capable of lowering its pest status in the US (Thornton, 2004), but appears to have a rich complex of natural enemies in Asia (Britton et al., 2002; Pemberton, 1996).

Despite its important exotic weed status, little is known about insects feeding on kudzu in its native range. Studies in China have generally focused on how to utilize this species and on its growth and ecology (An et al., 1994; Chen and Zhang, 1985; Keung and Vallee, 1998; Shao, 1993; Yang et al., 1996; Zhang, 1987; Zhang and Ye, 1990). Tayutivutikul and Kusigemati (1992) provided a list of insects associated with kudzu in Japan, and Tayutivutikul and Yano (1989, 1990) studied the biology of two kudzu-feeding insects, *Chauliops fallax* (Hemiptera: Lygaeidae) and *Megacopta punctissimum* (Hemiptera: Plataspidae). In addition, six fungal diseases of kudzu have been reported, mostly in China (Britton et al., 2002; Zidak and Backman, 1996). Pemberton (1996) reported an abundance of natural enemies of kudzu in China and elsewhere in Asia, and noted that good potential exists for biological control of kudzu in the US. Other scientists who visited China agreed and encouraged the initiation of a biological control research program. Therefore, a cooperative program funded by the USDA Forest Service was initiated in 1999 to survey the natural enemies of kudzu in China, with a final goal of finding potential biocontrol agents for kudzu in the US. Here we report results of a three-year survey of insects on kudzu foliage, seed, stems, and roots, with the aim of establishing basic information about insect communities on kudzu in China and identifying species that may have potential as biological control agents in the US. Preliminary information on impacts of different feeding guilds on kudzu in China is also reported. In addition, we report results of a survey of diseases of kudzu in southern China.

2. Materials and methods

2.1. Survey sites

Surveys focused on three sites in Anhui Province, China, because a computer software climate-matching program (Climex, Hearne Scientific Software, Melbourne, Australia) indicated that this was the province most similar in climate to Atlanta, Georgia. One site was in Qianshan (coordinates 116.55, 30.74, elevation approximately 150 m), south of the Yangtze River, which distinctly delineates flora and fauna in China. A second site was in Xuancheng (118.79, 30.88, elevation approximately 400 m), north of the Yangtze River, and another in Jinzhai (115.84, 31.47, elevation approximately 450 m), located deep in the Dabieshan

Mountains. The latter two sites were surrounded by pine plantations. All Anhui sites were in mountainous regions, where most kudzu in China occurs because of intensive farming in lowland areas. A fourth survey site was established in Guangdong Province, which is much further south and warmer than the Anhui mountain sites. This site (Longyandong, coordinates 113.32, 23.22, elevation approximately 50 m) was located in agricultural land mixed with pine plantations.

2.2. Systematic sampling

At each site, five root crowns of kudzu were randomly selected for sampling, marked with stakes and surrounded by a circle of colored tape and a sign to prevent human disturbance and for ease of relocation. At each sample date, the surveyor followed the same path to avoid trampling and damaging vines draped along the ground. The Qianshan site was surveyed for 3 years (1999–2001), Xuancheng and Guangdong for 2 years (1999–2000), and the Jinzhai site for one year (1999). At all sites, surveys were conducted at 10–20 day intervals from May to November. Usually 4–5 h were spent at each site, but sometimes an entire day and night were spent to observe insects that fed at night. Collection of kudzu-feeding insects was conducted by hand-picking, aspirating from kudzu plants, sweep-netting, and in some cases caging and rearing. When immature insects were found, they were collected in a plastic bag together with the plant part on which they were feeding and taken back to the laboratory at the Department of Entomology, Anhui Agricultural University, for rearing to the adult stage and further species identification.

Most of the insect species were identified by Professor Cai Ping (Anhui Agricultural University). Some Chrysomelidae were identified by Professor Yang Xingke (Institute of Zoology, Chinese Academy of Sciences [CAS]), some Cerambycidae were identified by Professor Sun Jianghua, and some Hymenoptera were identified by Professor Yuan Decheng (Institute of Zoology, CAS). References used were Economic Insect Fauna of China, edited by the Editorial Committee of Fauna Sinica, Academia Sinica (Ge, 1966; Ge et al., 1984; Jinag et al., 1985; Liu, 1963; Liu and Bai, 1977; Pu, 1980; Tan et al., 1985; Yu et al., 1996; Zhang, 1985, 1995; Zhao and Chen, 1980). Host range information, where known, was obtained from these same references.

2.3. Foliage damage

Defoliation and defoliators were recorded using a 30 × 30 cm quadrat sampler, hand catching, and net collection, plus sweep-netting over the kudzu. On the first two sample dates each year, defoliation was estimated by averaging defoliation for all leaves on all stems from each root crown, while on the remaining sample dates, defoliation was estimated by using the quadrat sampler, randomly selecting three locations in three different directions from each root crown. Five root crowns were sampled at each site. At each location, we placed the quadrat sampler over kudzu leaves and estimated the average defoliation of all leaves within the boundary of the quadrat by comparing them with a prepared pictorial graph. Only leaves that were more than 50% inside the quadrat boundaries were included. Between 5 and 25 leaves were included in each 30 × 30 cm sample.

2.4. Terminal damage

For each root crown, three side branches were randomly selected, and all terminals on those branches were checked for signs of insect feeding damage such as clipping. Any insects feeding on these terminals were collected.

2.5. Stem damage

On the first two sample dates each year, stem damage (signs of insect feeding within stems, oviposition, etc.) was recorded on all vines from each root crown. On the remaining sampling dates, we estimated damage by randomly selecting one vine from each root crown. For each vine, damage on the main stem and on three branches spaced equidistant along the main stem was recorded. Damage was described and we noted whether the vine was dead above the area of damage. For each type of stem-borer damage that was observed, a cage was placed around the vine until the adult emerged, and adults were collected for identification.

2.6. Root damage

From December to March, 40–200 roots were dug in the sample plots and in randomly selected sites surrounding these plots to survey for root damage. Adult insects found in galleries in the roots were collected for identification, and larvae were returned to the laboratory with pieces of root for rearing to the adult stage. The diameter of each root and the diameters of insect tunnels found in the roots were measured and recorded.

2.7. Seed damage

An insect exclusion treatment consisting of a closed cage over a raceme was compared with an uncaged raceme to evaluate the impact of insect herbivory on kudzu seeds. For this trial, just before caging, older pods were removed while newly formed pods were retained and racemes were cut off just above the new pods to prevent further flowering. Cages were constructed of organdy (64 × 80 threads per cm, 100% polyester), sewn into sleeves (25 cm long × 14 cm diameter) with a 7-cm opening through which racemes were inserted. The cages were tied at their bases with plastic-coated tie wire and labeled with aluminum tags. Six replicates were placed along a transect measuring approximately 75 m in Anhui Province in 2000. When seeds had reached maturity (about 8 weeks), dried racemes were removed, placed in plastic bags, and taken back to the laboratory. The length of pods was measured and seeds were hulled from the pods and counted. Healthy, infested, and total numbers of seeds from each replicate were recorded. In addition, during mid to late October, we collected all seed pods from each of the five plants that had been sampled at each site. These seeds were X-rayed and those with damage were put in rearing containers, with some dissected for further observation. Numbers of healthy and infested seeds were recorded, and emerged adults were identified.

2.8. Disease survey

Diseased foliage was collected at the Guangdong site and at the Qianshan site in Anhui Province, when observed during systematic insect sampling. Seedlings were not surveyed for disease, nor was disease severity assessed. Foliage was collected into an ice chest and returned to the laboratory. Pathogens were identified by Dr. Zide Jiang, plant pathologist at South China Agricultural University, Guangzhou Province.

2.9. Data analysis

Data on foliar damage, root damage, pod length and seeds per pod were analyzed using one-way ANOVA after testing whether the data were normally distributed (SPSS Inc., 1999). Data on terminal clipping, stem damage and seed damage were analyzed using Chi-square tests (SAS Institute, 1998).

3. Results

3.1. Insect diversity on kudzu

A total of 116 phytophagous species in 31 families and 5 orders were collected from kudzu in Anhui and Guangdong Provinces from 1999 to 2000 (Table 1). Insects were found in six different feeding guilds: foliage, sap, stem, terminal, seed and root feeders (Table 2). Insect diversity in China was greater than that in the US, where only three feeding guilds of arthropods were found associated with kudzu, with no root, stem or terminal-feeding insects (Thornton, 2004; Table 2).

3.2. Foliage-feeding insects

Foliage-feeding insects from kudzu in China included 37 species from 15 families. The species that appeared to have the greatest impact on the plant were two chrysomelid beetles, *Gonioctena tredecimmaculata* (Jacoby) and *Brachyphora nigrovittata* Jacoby, and an argid sawfly, *Arge* sp. The extent of defoliation varied from site to site, from year to year, and over the course of the growing season. In Qianshan, Anhui Province, defoliation averaged 4–6% in May each year, increasing to a peak of 12–18% in late June–early July (Fig. 1A). Defoliation was higher in Xuancheng, averaging over 30% at some sample dates in June or July each year (Fig. 1B). Defoliation in the southern province, Guangdong, was surveyed for a longer period, and was highest early in the growing season (Fig. 2), averaging about 20% in 1999 and 10% in 2000 in June and generally declining over the season (Fig. 1C). The mean percent defoliation for kudzu per year among all plots and all years of study was 13.3 ± 1.9 %.

3.3. Terminal-clipping insects

Two beetle species, *Ornatalcides* (*Mesalcidodes*) *trifidus* (Pascoe) (Coleoptera: Curculionidae) and *Deporaus* sp. (Coleoptera: Attelabidae), fed on shoots causing terminal death. Shoot clipping activity varied significantly over the season in both Xuancheng, Anhui Province ($\chi^2 = 78.4581$, $P < 0.0001$, $N = 692$) and Guangdong ($\chi^2 = 72.5796$, $P < 0.0001$, $N = 265$) in 2000. In Xuancheng, new shoots were clipped at a relatively high rate (~20–40%) from June through October, while at Guangdong terminal clipping rose to a peak of about 90% of all new shoots clipped in mid- to late-August 2000 (Fig. 2).

3.4. Stem insects

Insects infesting kudzu stems were primarily the cerambycid species, *Paraleprodera diophthalma* (Pascoe), *Atimura japonica* Bates, and *Pterolophia* spp., and a buprestid species, *Chalcophora japonica* Gory. These insects either fed on phloem or bored into the stems causing vine death. Overall, nearly half of all vines were found to have stem damage, varying at different sites and over the season. In Qianshan, between 65 and 80% of all stems showed evidence of damage in 1999, while in 2001 stem damage ranged from 25 to 55% of stems (Fig. 3).

3.5. Root insects

Two species of insects were found attacking kudzu roots, the cerambycid species *P. diophthalma* and *Aristobia hispida* (Sanders). A total of 198, 48, and 44 roots were dug in Qianshan, Xuancheng, and Guangdong, respectively, and 31.5, 62.5, and 64.4% of these roots were infested by cerambycid larvae. The diameters of uninfested and infested kudzu roots and of insect tunnels in infested roots were measured in Qianshan and Guangdong. In Qianshan, healthy (uninfested) roots had an average diameter of 4.7 cm, while insect-infested roots fell into two apparent categories, either significantly larger (mean of 6.7 cm diameter) or significantly smaller (mean of 3.3 cm diameter) than uninfested roots (Table 3A). Tunnel diameters were significantly larger in the large infested roots than in the small infested roots as well. In Guangdong, all of the roots collected were relatively small, and there was no significant difference in the root diameters of healthy and infested roots (Table 3B).

Table 1
Phytophagous insects collected from kudzu in China, 1999–2001

Order[a] Family[a]	Species	Freq[b]	Stage found[c]	Feeding guild	Host range[d]
Orthoptera					
Acrididae	*Chondracris rosea* (De Geer)	R	A	Foliage	Po
	Paratonkinacris vittifemoralis You et Li	R	A	Foliage	Unknown
Gryllidae	*Oecanthus sinensis* Walker	R	A	Foliage	Po
Hemiptera (S.O. Heteroptera)					
Berytidae	*Yemma exilis* Horvath	R	A	Sap	Unknown
Coreidae	*Acanthocoris scaber* (L.)	R	A	Sap	Po
	Anoplocnemis phasiana (F.)	R	A	Sap	Po
	Cletus punctiger Dallas	R	A	Sap	Po
	Cletus trigonus (Thunberg)	R	A	Sap	Unknown
	Hygia opaca (Uhler)	R	A	Sap	Unknown
	Homoeocerus marginellus Herrich-Schaeffer	R	A	Sap	Po
	Liorhyssus hyalinus (F.)	R	A	Sap	Unknown
	Mictis angusta (Hsiao)	R	A	Sap	Po
	Paraplesius unicolor Scott	R	A	Sap	Po
	Riptortus pedestris (F.)	R	A	Sap	Unknown
Lygaeidae	*Chauliops bisontula* Scott	C	A,N	Sap	Po
	Chauliops fallax Scott	O	A	Sap	Po
	Macropes bambusiphilus Zheng	R	A	Sap	Unknown
	Malcus elongatus Stys	R	A	Sap	Po
	Malcus sinicus Stys	R	A	Sap	Po
	Nysius ericae Schilling	O	A	Sap	Po
	Tropidothorax elegans (Distant)	R	A	Sap	Po
Miridae	*Adelphocoris quadripunctatus* (F.)	R	A	Sap	Po
	Halticus tibialis Reuter	R	A	Sap	Po
Pentatomidae	*Aspongopus chinensis* Dallas	R	A,N	Sap	Unknown
	Cyclopelta obscura (Lepeletier-Serville)	R	A,N	Sap	Unknown
	Halyomorpha halys (Stal)	R	A,N	Sap	Unknown
	Nezara viridula (L.)	R	A	Sap	Po
	Palomena amplifioata Distant	R	A	Sap	Po
Plataspidae	*Cydnocoris russatus* Stal	R	A	Sap	Po
	Megacopta cribraria (Fabricius)	C	A,N	Sap, Seed	Po
	Megacopta distanti (Montandon)	O	A	Sap	Mo
	Megacopta sp.	R	A	Sap, Seed	Ol
	Pyrrhopeplus cardulis (Stal)	R	A	Sap	Po
Pyrrhocoridae	*Sclomina erinacea* Stal	R	A	Sap	Po
Urostylidae	*Urostylis annulicornis* Scott	R	A	Sap	Unknown
Hemiptera (S.O. Auchenorrhyncha)					
Cicadellidae	*Aguriahana zheensis* Cai et He	R	A	Sap	Mo
	Amrasca biguttula (Ishida)	R	A	Sap	Po
	Apheliona fenuginea (Matsumura)	O	A	Sap	Ol
	Bothrogonia sinica Yang et Li	R	A	Sap	Po
	Cicadella viridis (L.)	R	A	Sap	Po
	Empoasca decedens Paoli	R	A	Sap	Mo
	Exitianus indicus (Distant)	R	A	Sap	Unknown
	Hishimonus sellaus (Uhler)	R	A	Sap	Unknown
	Kolla paulula (Walker)	R	A	Sap	Po
	Krisna nigromarginata Cai et Shen	R	A	Sap	Ol
	Kutara nuchali Jacobi	R	A	Sap	Mo
	Norva anufrievi Emeljanov	R	A	Sap	Unknown
	Paivanana indra (Distant)	R	A	Sap	Unknown
	Paralaevicephalus nigrifemoratus (Matsumura)	R	A	Sap	Mo
	Paramesus mokanshanae Wilson	R	A	Sap	Unknown
	Riseveinus sinensis (Jacobi)	R	A	Sap	Mo
	Sophonia rubrolimbata (Kuoh et Kuoh)	O	A	Sap	Unknown
	Sophonia rufolineata (Kuoh)	R	A	Sap	Mo
	Tautoneura arachisi (Matsumura)	C	A	Sap	Ol
	Tituria colorata Jacobi	R	A	Sap	Mo
	Yanocephalus yanonis (Matsumura)	R	A	Sap	Po

Table 1 (*continued*)

Order[a] Family[a]	Species	Freq[b]	Stage found[c]	Feeding guild	Host range[d]
Delphacidae	*Sogatella furcifera* (Horvath)	R	A	Sap	Unknown
Membracidae	*Gargara* sp.	R	A	Sap	Po
	Gargara genistae (F.)	R	A	Sap	Unknown
	Tsunozemia mojiensis Matsumura	R	A	Sap	Unknown
Fulgoridae	*Lycorma delicatula* White	R	A	Sap	Po
Ricaniidae	*Ricania speculum* (Walker)	R	A	Sap	Po
	Ricania taeniata Stal	R	A	Sap	Unknown
Coleoptera					
Attelabidae	*Deporaus* sp.	C	A	Terminal	Mo
	Deporaus unicolor Rodofs	C	A	Terminal	Unknown
Bostrychidae	Unknown	R	A	Stem	Unknown
Buprestidae	*Agrilus* sp.	C	A,P,L	Foliage, Stem	Mo
	Chalcophora japonica Gory	R	L	Stem	Unknown
Cerambycidae	*Aristobia hispida* (Sunders)	C	A,L	Root	Po
	Atimura japonica Bates	O	L	Stem	Po
	Mesosa irrorata Gressitt	O	L	Stem	Po
	Oberea ferruginea Casey	O	L	Stem	Unknown
	Paraleprodera diophthalma (Pascoe)	O	L,P	Root, Stem	Ol
	Phytoecia rufiventris Gautier	R	L	Stem	Po
	Pterolophia annulata (Chevrolat)	O	L	Stem	Po
	Pterolophia serricornis Gressitt	O	L	Stem	Po
	Ropica sp.	R	L	Foliage	Unknown
	Xenolea sp.	O	L	Stem	Unknown
	Xylariopsis sp.	O	L	Stem	Po
Chrysomelidae	*Altica cyanea* (Weder)	R	A	Foliage	Unknown
	Borowiecius ademptus (Sharp)	C	L	Seed	Unknown
	Brachyphora nigrovittata Jacoby	C	A,L	Foliage	Po
	Dactylispa angulosa (Solsky)	R	A	Foliage	Unknown
	Colposcelis signata (Matschulsky)	C	A,L	Foliage	Po
	Dercetina sp.	R	A	Foliage	Po
	Gonioctena tredecimmaculata (Jacoby)	C	A,L	Foliage	Mo
	Japonitata sp.	R	A	Foliage	Po
	Melanotus sp.	R	A	Foliage	Unknown
	Oides tarsatus (Olivier)	R	A	Foliage	Po
	Sagra femorata purpurea Lichtenstein	C	A	Stem	Po
	Smaragdina nigrifrons (Hope)	R	A	Foliage	Po
Coccinellidae	*Epilachna chinensis* (Weise)	R	A	Foliage	Po
Curculionidae	*Curculio dieckmanni* (Faust)	R	A	Foliage	Po
	Episomus chinensis Faust	O	A	Foliage	Unknown
	Episomus turritus (Gyllenhal)	O	A	Foliage	Unknown
	Eugnathus sp.	R	A	Foliage	Unknown
	Macrocorynus capito (Faust)	R	A	Foliage	Po
	Macrocorynus plumbeus Formanek	R	A	Foliage	Po
	Ornatalcides (Mesalcidodes) trifidus (Pascoe)	O	A	Stem, Terminal	Po?
Meloidae	*Epicauta obscurocephala* Reitter	C	A	Foliage	Po
	Epicauta chinensis Laporte	C	A	Foliage	Po
Scarabaeidae	*Anomala corpulenta* Motsch	R	A	Foliage	Po
	Anomala straminea Semenov	R	A	Foliage	Po
	Anomala sulipennis Faldermann	R	A	Foliage	Po
	Popillia mutans Newman	R	A	Foliage	Po
Hymenoptera					
Argidae	*Arge* sp.	C	L	Foliage	Mo?
Tanaostigmatidae	*Tanaostigmodes puerariae* sp.nov.	C	A	Foliage, Gall	Unknown
Lepidoptera					
Amatidae	*Amata germana* Felder	R	A	Foliage	Po
Hepialidae	*Phassus sinifer sinensis* Moore	O	L	Foliage	Unknown
Nymphalidae	*Argyronome ruslana* Motschulsky	R	A	Foliage	Unknown
	Pareda vesta F.	C	A	Foliage	Unknown
	Polygonia chaohualbum hemigera Butler	C	A	Foliage	Unknown
Pyralidae	*Maruca testulalis* Geger	C	L	Seed	Po

(*continued on next page*)

Table 1 (*continued*)

Order[a] Family[a]	Species	Freq[b]	Stage found[c]	Feeding guild	Host range[d]
Sphingidae	*Clanis bilineata* (Walker)	O	L	Foliage	Ol
	Clanis bilineata tsingtauica Mell	R	A	Foliage	Unknown

[a] Orders, suborders (Hemiptera only), and families as in Triplehorn and Johnson (2005).
[b] Relative frequency: R, rare, taken at a few sites, usually in small numbers; O, occasionally collected at sites; and C, common, taken at most sites.
[c] L, larva; P, pupa; A, adult; and N, nymph.
[d] Po, Polyphagous, feeds on plants from other families in addition to Fabaceae; Ol, Oligophagous, feeds mainly on Fabaceae; Mo, Monophagous on kudzu. Host range based on Economic Insect Fauna of China (references in text).

Table 2
Numbers of phytophagous arthropod species in different feeding guilds recorded from kudzu in China and in the US

Feeding guild	United States[a]		China[b]	
	No. families	No. species	No. families	No. species
Foliage feeders	13	N/A	15	37
Seed feeders	2	N/A	2	3
Sap feeders	14	N/A	13	60
Stem borers	0	0	5	14
Terminal feeders	0	0	2	3
Root feeders	0	0	1	2

[a] Data from Thornton (2004). N/A, not available.
[b] Species found infesting two different plant parts were counted in both guilds.

3.6. Seed damage

Seed feeders in China included a bruchine beetle (Chrysomelidae, subfamily Bruchinae) and a pyralid moth species. When insects were excluded during pod formation, seed damage was significantly lower than in the uncaged treatment ($\chi^2 = 107.9315$; $P < 0.001$; Table 4). From an additional 415 pods that were collected from survey plots, a total of 2408 seeds were examined. Of these, 1197 (49.7%) contained bruchine larvae, 319 (13.2%) contained insect pupae, and 442 (18.4%) of the seeds were shriveled (not fully developed), leaving only 450 (18.7%) apparently healthy seeds.

3.7. Diseases

The most commonly observed disease of kudzu was "imitation rust," caused by *Synchytrium minutum* [= *S. puerariae* (P. Henning) Miyabe]. In one location in Anhui province, disease severity was intense enough to cause vine mortality. The next most common disease was leafspot. Several leafspot fungi were identified, including *Pseudocercospora puerariicola* (Yamam.) Deighton (angular leafspot), *Cercospora puerario-thomsona* Chen & Chi (brown spot), *Phomopsis* sp., *Colletotrichum lindemuthianum*, and *Colletotrichum* sp. (anthracnose).

4. Discussion

Insect surveys on kudzu in China revealed a rich phytophagous insect fauna, with 116 species recorded, in six insect guilds attacking different parts of kudzu. In the US insects in only three insect guilds are known to infest kudzu (Thornton, 2004).

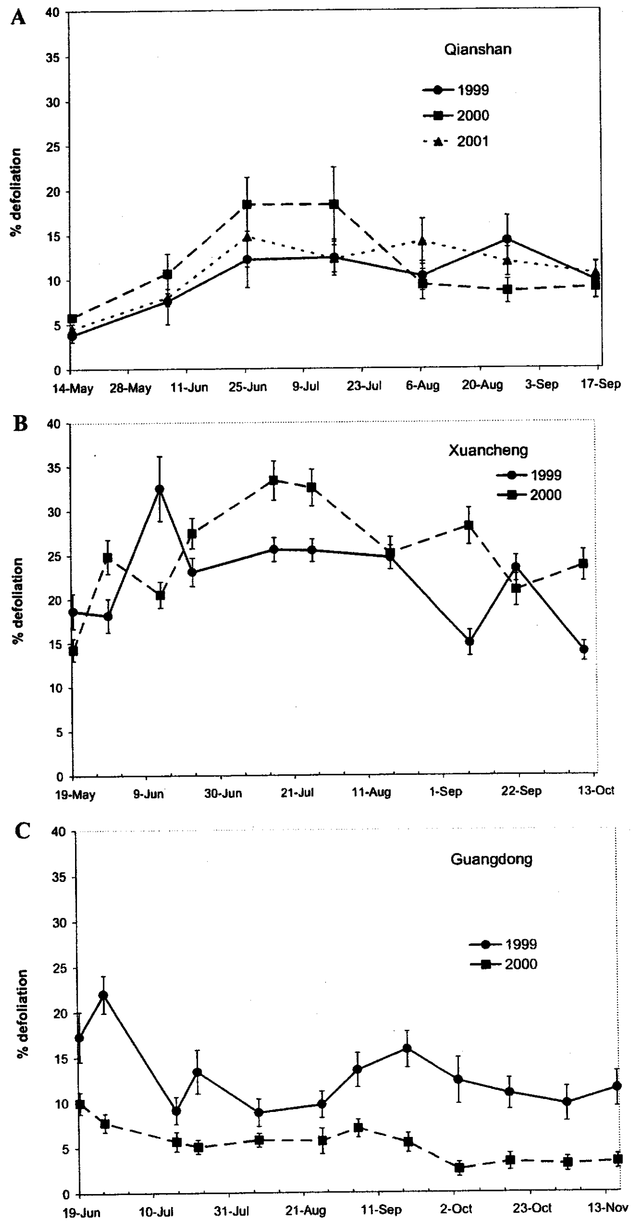

Fig. 1. Kudzu defoliation in (A). Qianshan, 1999–2001; (B) Xuancheng, 1999 and 2000; and (C) Guangdong Province, 1999 and 2000. Means ± SEM are shown.

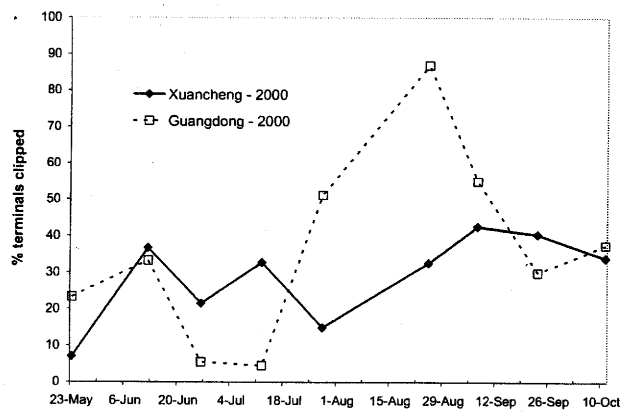

Fig. 2. Percent of kudzu shoots with terminals clipped (primarily by two beetle species, *Ornatalcides (Mesalcidodes)* [Curculionidae] and *Deporaus* sp. [Attelabidae]), Xuencheng and Guangdong Province, 2000.

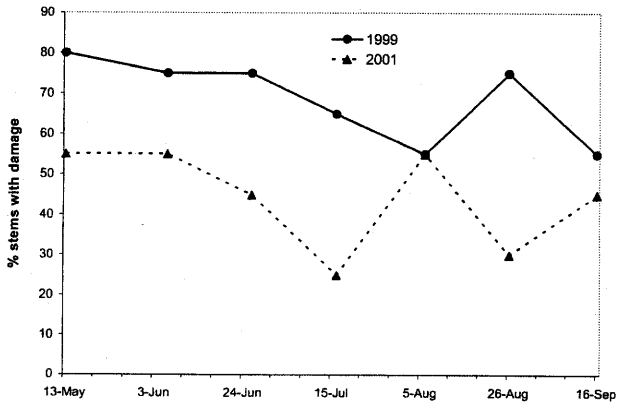

Fig. 3. Percent of kudzu stems with damage (primarily by stem-boring or phloem-feeding Cerambycidae and Buprestidae), Qianshan, 1999 and 2001.

A total of 37 foliage-feeding insect species from 15 families were found on kudzu in China, with two chrysomelids and a sawfly apparently causing the most extensive defoliation. Thornton (2004) reported that all leaf-feeding species on kudzu in the US were generalist herbivores. In China, although most of the species were generalists, we found several species primarily or solely infesting leaves of kudzu.

In the US, no terminal feeders or stem borers have been observed (Thornton, 2004), while in China many insects attack kudzu terminals and stems. The damage caused by these insects can be severe, with up to 90% of new terminals clipped and 50–80% of stems damaged at some sites.

No root-infesting insects have been found on kudzu in the US, while in China roots were heavily damaged by cerambycid beetles. In China, these insects infest about 50% of roots, and were found to attack both small (young) and large (old) roots, with even large roots severely damaged. In our samples from Qianshan, small and large roots were more likely to be attacked than intermediate sized roots. Further study is needed to determine whether this reflected damage by two different species, or by two different instars of the same species.

Kudzu seeds were also heavily damaged by insects in China, with about 70% of seeds caused to be nonviable. Insects attacking seeds included a pyralid moth and a bruchine (chrysomelid) beetle. Kidd (2002) also found heavy damage to uncaged kudzu seed in North Carolina, with only 19% of non-caged seeds free of insect damage compared with 91% of caged seeds. Seed damage in her study was attributed to several generalist hemipterans and a naturalized bruchine of Asian origin, *Borowiecius ademptus* (Sharp). Similar results were reported by Thornton (2004).

"Imitation rust" was the most common disease observed on kudzu in China. This disease has only been reported on *P. montana* var. *lobata* and *P. thomsonii* (Feng et al., 1999; Tai, 1979). The causal pathogen *S. minutum* was described as *Uredo minuta* by Saccardo in 1893, probably because the brilliant orange sori look like rust pustules. Kusano recognized the fungus as a chytrid in 1902, and described the life cycle and host/parasite relationship (Karling, 1964). This fungus attacks leaves, stems, flowers, and seedpods of kudzu, causing erumpent golden sori of unicellular, flagellate zoospores. Severe infection causes leaf distortion and necrosis and rough and swollen stems, with significant occlusion of the vascular tissue.

Table 3
Relationship between kudzu root diameter and insect attack

Root types	N	Root diameter (cm)	Tunnel diameter (cm)	
(A) Qianshan, Anhui Province				
Insect-infested (large)	11	6.7 ± 0.6 a	1.6 ± 0.08 a	
Healthy (uninfested)	121	4.7 ± 0.1 b		
Insect-infested (small)	42	3.3 ± 0.1 c	1.3 ± 0.03 b	
F		32.221	19.094	
P		<0.001	<0.001	
		Root diameter (cm)		
		Base	Center	Terminal
(B) Guangdong Province				
Healthy (uninfested)	16	2.1 ± 0.5 a	3.2 ± 0.9 a	1.5 ± 0.4 a
Infested	25	1.6 ± 0.2 a	2.6 ± 0.4 a	1.4 ± 0.2 a
F		1.242	0.584	0.086
P		0.271	0.449	0.771

Data shown as means ± SEM. Means followed by different letters in each column are significantly different ($P < 0.05$, Scheffe's test).

Table 4
Effects of insects on seed damage in Qianshan, Anhui Province

Treatment	% of damaged seeds
Control (uncaged)	64.7
Insects excluded (caged)	36.3
P	<0.001

$N = 1429$ seeds from uncaged and 424 seeds from caged treatments. Data analyzed using χ^2 analysis.

From an ecological perspective, it seems likely that the abundant and diverse insect fauna along with the various pathogens that we observed on kudzu constitute an important check on the growth and spread of kudzu in China, while the relatively sparse fauna in the US contributes to its invasive habit and pest status there. From a biological control perspective, defoliators, terminal or stem feeders, and root-infesting species should all be considered as potential control agents. Seed feeders should not be considered, because kudzu in the US already experiences high levels of seed destruction, and because most spread of kudzu in the US is vegetative.

The most important hurdle for any potential biological control agent to cross before it can be imported into the US will be demonstration of sufficient host specificity. Although no *Pueraria* species other than kudzu are present on the continental US, there are several species in different genera in the same subtribe (Glycininae) as kudzu, with the introduced crop species *Glycine max* (L.) Merr. (soybean) of greatest economic importance. Many other economically and ecologically important plants occur within the same family (Fabaceae = Leguminoseae) as kudzu. A proposed test list was submitted to the Technical Advisory Group for Biological Control of Weeds (TAG) in 2004 (Birdsall and Hough-Goldstein, 2004), detailing the breadth of plant taxa that must be tested before a potential agent can be approved for release.

The imitation rust fungus that we recovered shows potential as a biological control agent, but much work remains to establish its host specificity. The first step in this process will be the development of an artificial inoculation technique on kudzu. Among the insect species that we collected on kudzu, several are thought to be monophagous or oligophagous based on observations and on Chinese taxonomic references, and therefore will be tested either in China or in quarantine in the US. Following are the most promising species identified to date.

Gonioctena tredecimmaculata (Jacoby) (Coleoptera: Chrysomelidae) is a voracious consumer of kudzu foliage, both as adults and as larvae, and is currently being studied in quarantine in Newark, DE, USA. In a recent taxonomic review, Bezděk (2002) concluded that the species usually identified as *G. tredecimmaculata* is actually made up of five independent species. Based both on distribution (eastern China, not Sichuan) and morphology, the species under study is the true *G. tredecimmaculata*. Host plants for the *Gonioctena* group have been reported as *Mucuna* sp. and *P. montana* by Russian authors, but have not been reported specifically for the Chinese species (Bezděk, personal communication, 2004).

The sawfly, *Arge sp.* (Hymenoptera: Argidae), which is also a defoliator, and the leafroller weevil, *Deporaus* sp. (Coleoptera: Attelabidae), a terminal clipper, must be identified to species before they can be fully evaluated. Preliminary host-range tests in China indicate potential monophagy.

Ornatalcides (*Meslcidodes*) *trifidus* (Pascoe) (Coleoptera: Curculionidae), a terminal clipper and gall-forming weevil, reportedly feeds on *Lespedeza* spp. (Zheng et al., 2004) in addition to kudzu, but this needs to be confirmed. In preliminary tests in China, this weevil fed on soybean as adults but did not complete its life cycle on soybean.

Finally, *P. diophthalma* (Pascoe) (Coleoptera: Cerambycidae) was found infesting kudzu stems and roots in this study, causing severe damage. There appears to be no available literature on its host specificity, and host specificity trials have not yet been conducted.

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